SUBSURFACE IMAGING OF LAVA TUBES
Roadway Applications

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U.S. Department of Transportation
Federal Highway Administration

Federal Lands Highway
Commitment to Excellence

Central Federal Lands Highway Division
12300 West Dakota Avenue
Lakewood, CO 80228

FOREWORD

The Federal Lands Highway (FLH) promotes development and deployment of applied research and technology applicable to solving transportation related issues on Federal Lands. The FLH provides technology delivery, innovative solutions, recommended best practices, and related information and knowledge sharing to Federal agencies, Tribal governments, and other offices within the FHWA.

At many sites where road projects are planned by the FLH, unknown or undetected lava tubes (subsurface voids) may be present. To help quantify issues related to unknown voids, CFLHD undertook a preliminary investigation into non-invasive geophysical methods aimed at (1) characterizing the presence and vertical/horizontal extent of voids, (2) determining the most suitable geophysical methods for specifically conducting roadway surveys in terms of detection capabilities vs. feasibility (cost) vs. time constraints, and (3) identifying the range of applications nationwide

This study includes background information of multiple geophysical methods and there ability to detect voids, a review of geophysical data collected over lava tubes at Lava Beds National Monument, and the results from the data. Conclusions and recommendations for economically and accurately locating lava tubes were made.

Notice

Quality Assurance Statement

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16. Abstract

The Central Federal Lands Highway Division (CFLHD), FHWA, located in Denver, CO, is primarily responsible for the rehabilitation, reconstruction, and repaving of National Forest and Park roads in the western states region. At many sites, such as the Lava Beds National Monument (LBNM) in northern California, there are concerns that unknown near-surface voids pose possible risks to roadway construction activities, the long-term stability and maintenance of the roadway, and to public safety. To help quantify issues related to unknown voids, CFLHD undertook a preliminary investigation into non-invasive geophysical methods aimed at (1) characterizing the presence and vertical/horizontal extent of voids, (2) determining the most suitable geophysical methods for specifically conducting roadway surveys in terms of detection capabilities vs. feasibility (cost) vs. time constraints, and (3) identifying the range of applications nationwide.

This report contains the details of geophysical surveys performed at the LBNM. The geophysical surveys were preformed over several areas with known lava tubes. This report provides the geological site conditions, overviews of the geophysical methods, summary of the results, and overall recommendations that should be considered for future void detection.

17. Key Words
GEOPHYSICAL SURVEYS, MAGNETIC, ELECTRICAL RESISTIVITY, ELECTRICAL CONDUCTIVITY, HIGH RESOLUTION SHEAR WAVE REFLECTION, GROUND PENETRATING RADAR, VOIDS, LAVA TUBES

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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EXECUTIVE SUMMARY

The purpose of this report is to provide information on geophysical techniques to detect the presence of shallow-subsurface voids where road projects are planned. Determining subsurface conditions for road projects will significantly reduce the risk to roadway construction activities, provide improved long-term stability and maintenance of the roadway, and improve public safety. Identifying these voids will potentially preserve them from damage. It will also provide planners with information on corridor alignment to mitigate impacts.

In order to accurately and economically locate near-surface voids that may affect roadway stability, the FHWA-CFLHD in coordination with Blackhawk investigated a variety of geophysical techniques at Lava Beds National Monument (LBNM) in northern California. The main objectives were to: (a) detect the presence of subsurface voids under specific geologic settings, (b) detect and characterize the vertical/horizontal extent of the voids, (c) determine the most economical and efficient (time effective) geophysical method(s) to use during roadway site investigations, and (d) identify the range of applications of such methods nationwide.

Geophysical techniques were chosen for near-surface void detection because they are non-intrusive and cost- and time-effective methods. In general, their accuracy and resolution depend on the depth of investigation and geological factors (for most geophysical methods, resolution decreases as depth increases).

The LBNM area was chosen as the site for these investigations for the following reasons: (a) the existence of many well-mapped caves that vary both in size and depth beneath the ground surface and (b) future roadwork is planned in LBNM and the results may be beneficial to this work.

Geophysical data were collected at the site using Ground Penetrating Radar (GPR), Magnetics, High Resolution Shear Wave Seismic Reflection (HRSW), Electrical Resistivity (ER), and Electrical Conductivity methods. Each site has known underground void geometries and locations. This information was used to assess the accuracy of each applied geophysical method for void detection at LBNM.

The results of the investigation indicated that some of the geophysical methods were effective in detecting voids, while other methods were limited due to the localized geological setting and void geometries. Depending on site conditions, such as subsurface geology or void size and depth, when a combination of methods were used, there was a greater chance of effectively delineating the location and orientation of the voids. The combined GPR and magnetic methods were the most economical and least time consuming for detecting voids whose depths range between 0 to 9 m (0 to 30 ft). Magnetic surveys should be performed first as a reconnaissance tool in order to locate the position of magnetic anomalies that may indicate the presence of potential voids. A focused GPR survey would then be conducted to evaluate each magnetic anomaly and to determine the depth and lateral extent of the features.

This study includes information about the site geology, survey site descriptions, overview of the geophysical methods used, data acquisition parameters, and interpretations. The results of this study will be of interest to federal land managers who protect these types of features, highway designers, maintenance crews, geotechnical engineers, owners of roads constructed over old mine works, and utility crews; in general, whoever is interested in locating voids beneath roadways.

REPORT ORGANIZATION

The Executive Summary provides a summary of the geophysical study, results, and recommendations.

Chapter One provides a brief background on engineering problems related to the presence of voids beneath roadways and the geophysical methods used during the study.

Chapter Two outlines the regional location of the LBNM area and its geological background. The geological setting of investigative area is important when planning a geophysical survey.

Chapter Three describes the geophysical methods/techniques available to meet the study's objectives. Five geophysical methods were used at the LBNM site. The general background of the methods, data acquisition, advantages and limitations for mapping subsurface voids, and case studies for mapping subsurface voids are discussed.

Chapter Four details the geophysical surveys at LBNM. This chapter includes individual site descriptions, data analysis and interpretation, and comparisons of each method used at each site.

Chapter Five lists the results from the geophysical surveys at LBNM.

Chapter Six details the Quality Assurance and Quality Control activities performed in order to provide quality products and services.

Chapter Seven states the conclusions and recommendations derived from this report.

The certification and disclaimer, the acknowledgement, and references are listed at the end of the text.

Appendix A contains photographs from LBNM.

Appendix B lists survey parameters used at LBNM.

Appendix C contains GPR cross sections from the data collected at LBNM.

Appendix D contains electrical resistivity cross sections from the data collected at LBNM.

Appendix E contains high resolution shear wave cross sections from the data collected at LBNM.